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IMPLICATIONS OF POSSIBLE SHUTTLE CHARGING

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DEFENSE AND SPACE SYSTEMS GROUP

IMPLICATIONS OF POSSIBLE SHUTTLE CHARGING

1. INTRODUCTION

The importance of questions about spacecraft charging and associated phenomena have been recognized since the early 1960's. Numerous scientific and technical papers have been written, two conferences have been recently held and the proceedings published (Pike and Lovell, 1977 and Anonymous, 1979) and a satellite (SCATHA) has been flown with the primary objective of understanding charging and associated phenomena, for its description, see Stevens and Vampola (1978).

Some aspects of spacecraft charging have been intensely analyzed. Theoretical treatments of the potential of passive spacecraft (Al' pert, et al, 1965 and Kasha, 1969) have been successful in predicting the potential of passive spacecraft at synchronous orbit (Rubin and Garrett, 1979). It also has been predicted and experimentally verified that the potential of such spacecraft can be clamped to within a few volts of the plasma potential by use of an ion gun (Bartlett and Purvis, 1979). Similar analyses have been performed to determine to what extent rocket-borne accelerators will charge and predictions were made that indicated the accelerators might not be able to eject the electrons, however, such accelerators have been sucessful (see for example, Hess et al, 1971 and Winckler, 1974). The analysis of these questions of charging and neutralization of a large, primarily non-conducting, active vehicle in low earth orbit has only recently begun. One such analysis was reported earlier under this contract (Sellen, 1977); another is by Liemohn (1976). Wisely the SEPAC instrumentation includes a number of methods to neutralize the shuttle in the initial flight of SEPAC.

Other aspects of spacecraft charging have not been successfully analyzed. An example is the arcing resulting from differental charging that has been inferred from data from spacecraft at synchronons orbit and the resultant coupling into electronic devices.

Two analyses of shuttle charging have been performed and are reported here. The first predicts the effective collecting area of a wire grid, biased with the respect to the potential of the magnetoplasma surrounding it. The second predicts the intensity of broadband electromagnetic noise that would be emitted if surface electrostatic discharges occur between the Beta cloth and the wire grid that will be sewn onto it.

2. NEUTRALIZATION EFFICIENCY

In an effort to increase the area of grounded conductor exposed to the ionospheric plasma during the Spacelab 1 flight, wire will be sewn onto the exterior surface of the Beta cloth multilayer insulation that will cover parts of the Shuttle bay. This grounded wire grid is expected to draw electrons by electrostatic attraction from the plasma over an area larger than the area of the wire itself. A piece of the wire-Beta cloth combination was tested in a plasma chamber in Japan and the effective collection area was found to be about 10% of the total area (SEPAC Team, 1979). On shuttle, the effective collection area should depend on the plasma parameters and the shuttle potential, increasing as the potential becomes more positive.

As a model for the interaction between the plasma and the wire-Beta cloth combination let us assume that a wire is immersed in a uniform plasma, that the plasma electrons drawn to the wire come from only one side of it and that the plasma electrons can only be pulled from the magnetic lines of force to the wire when the electric field is equal to the $\vec{v} \times \vec{B}$ force.

First the potential distribution around a long cylinder in a plasma must be determined. Figure 1a shows the geometry. To determine the electric field near the cylinder, Poisson's equation must be solved. In this situation it is:

$$\nabla^2 \phi = \rho/\varepsilon_o$$

Where ϕ is the electrical potential, ρ is the charge density and ε_o is the permittivity of free space. It will be valid for $r \geq r_o$ and with the boundary condition that $\phi = \phi_o$ at $r = r_o$.

In cylindrical coordinates:

$$r^2 \frac{d^2\phi}{dr^2} + r\frac{d\phi}{dr} - \frac{r^2}{\lambda_D^2}\phi = 0$$

Where λ_D is the classical debye length

$$\lambda_D^2 = \frac{\epsilon_0 k\, T_e}{e^2 n_e},$$

K is Boltzman's constant, e is the elementary charge and T_e and n_e are the electron temperature and density. This equation is a type of Bessel equation. Its formal solutions are the modified Bessel functions $I_o\ (r/\lambda_D)$ and $K_o\ (r/\lambda_D)$. I_o is an increasing function of r and, therefore, is not a physical solution. K_o is a decreasing function of r and therefore is the correct solution,

$$\phi = a\, K_o\ (r/\lambda_D)$$

where a is determined by the boundary cordition. The electric field can be found using

$$\vec{E} = -\frac{d\phi}{dr}\hat{r}.$$

The wire to be used on Spacelab 1 is .020 - .030 inches in diameter (W. Baker, Private Communication, 1979). Using a diameter of .025 inches, $r_o = 3\times10^{-4}$ m. For a typical ionospheric density of $10^{11}\ m^{-3}$ and temperature of 2500 K, the debye length is .01 m. Applying the boundary condition gives

$$\phi = \frac{\phi_0}{3.5} K_o\ (100\ r) \qquad (1)$$

or

$$\vec{E} = -\frac{\phi_o}{3.5} K_o'\ (100\ r)\ \hat{r}$$

$$(2)$$

$$\vec{E} = \frac{\phi_o}{3.5} K_1\ (100\ r)\ \hat{r}$$

Since $K_o'\ (X) = -K_1\ (X)$.
Sketches of the behavior of ϕ and E are shown in Figure 1 b and c.

Assuming that the potential and electric field distributions around a wire that were determined above fairly accurately describe the conditions around the wire-Beta cloth combination, the collection

efficiency can be determined. The main source of electrons will be the thermal electrons. The thermal electrons will be constrained to move along the magnetic field lines (gyroradii of a few cm) until they move into a region of high electric field. If the shuttle charges, the wire on the Beta cloth will be at a high potential and will have an electric field around it. the force on an electron will be

$$\vec{F} = mq \quad (\vec{E} + \vec{v}x\vec{B})$$

and the electron will move primarily under the influence of the electric field (the collecting field) when the electric field term is larger than the $\vec{v} \times \vec{B}$ term. The magnitude of the $\vec{v} \times \vec{B}$ term is, on the average, about

$$|\vec{v} \times \vec{B}| \approx 1/2 \; |\vec{v}||\vec{B}| \quad .$$

For an average electron temperature of 2500 K ($v \approx 3.\ 2 \times 10^5$ m/sec) and an average magnetic field of 4×10^{-5} Wb/m^2,

$$|\vec{v} \times \vec{B}| \approx 6.4 \text{ volts/m}$$

In this model, a thermal electron will be considered "captured" by the wire when it enters an electric field higher than 6.4 volts/m. Figure 2 shows at what radius from a .3 mm radius wire immersed in a plasma with a density of 10^5 cm^{-3} and temperature of 2500 K will the electric field be 6.4 volts/m. Calculating the effective collecting area of a grid of . 3 mm radius wires, spaced 76.2 mm apart gives the data shown in figure 3. It shows that even for moderate potentials, the effective area is relatively large. For example, if the shuttle charges to 100 volts, the effective area should be about 40%. Therefore, if the shuttle does charge, the electrodynamics of the plasma should strongly stabilize and limit the potential, as long as the spacecraft potential does not go above about 10^5 volts, where the effective area becomes 100% and can increase no further.

3. ELECTROSTATIC DISCHARGES

As concluded in the last section, the wire-Beta cloth combination appears to act as a buffer against high vehicle potential. However, if the shuttle does charge to high potentials, the dielectric insulating surface of the Beta cloth which is exposed to the space plasma will gather electrons and may charge negatively with respect to shuttle ground unless the outer surface of the Beta cloth is a much better conductor than previous thermal blanket insulators. If the potential difference becomes large enough, electrostatic discharges might occur. Charging of exposed dielectric surfaces on satellites has been inferred from data from those satellites (Le Jeune, 1974) and has also been demonstrated in the laboratory (Robinson, 1979). Figure 4 shows the experimental configuration and data from Robinson (1979), giving the dielectric surface potential as a function of distance from a conducting, grounded, metal half-round clamped to a dielectric coated, grounded, conductor during exposure to a 20 kV electron beam. It shows dramatically that high electric fields along the dieletric are created in such situations.

When very intense electric fields are generated along the surface of a dielectric, electrostatic discharges can occur. Electrostatic discharges naturally emit electromagnetic waves which may cause upsets in nearby electronics. Balmain (1979) has studied surface discharges on metal backed mylar under electron beam irridiation and found a number of scaling laws which will aide in estimating the level of electromagnetic radiation expected. The pulse duration was found to depend on dielectric area with a power law relationship.

$$T \propto A^{-.55}$$

Scaling Balmain's (1979) data to a six inch square of dielectric (232 cm^2) gives a pulse time of about 350 nS. The pulse approximates one half of a wave so that the corresponding frequency is about 1.4 MHz. The actual current pulses shown in Balmain and pulses from similar tests by Rosen, et al (1972) have significant frequency content up to about 5 times the basic frequency or in this case 7 MHz. The frequencies emitted, if electrostatic discharges do occur between the Beta cloth and

and the wires, should be primarily in the 1.4 to 7 MHz range. These frequencies correspond to free space wavelengths between 40 and 200 meters which means that at the orbiter the near-fields will be the primary contributor to EMI. The near field electric field is given approximately by

$$E \simeq \frac{P}{4 \pi \epsilon_o r^3}$$

where P = ql is the dipole strength, q is the charge and l is the discharge length. A picture of a typical surface discharge in Balmain (1979) shows that a typical discharge length is 1/10 of the size of the dielectric. For the wire-Beta cloth combination planned for Spacelab 1 that length will be about .15m. Balmain (1979) determined that the released charge in a surface discharge is proportional to dielectric area.

$$\sigma \propto A$$

and scaling to our situation

$$q \simeq 4.5 \times 10^{-5} \text{ C.}$$

This gives a moment of

$$p = 7 \times 10^{-7} \text{ Cm}$$

and an electric field of

$$E = 6 \times 10^3 \text{ Volts/m}$$

at a distance of one meter. For the estimated bandwidth of about 6 MHz,

$$E/Bw = 10^9 \; \mu \text{ V/m MHz}$$

$$= 180 \text{ dB above } 1\mu\text{V/m MHz}$$

compared to a specification for the composite payload of 99 db at 1.4 MHz to 91 db at 7 MHz given in Figure 10.7.3.2-1 of ICD 2-19001. This is certainly a high level, but exists only during the discharges (if they occur) which last about 350 nS.

To estimate how often discharges might occur, the time for a charge build-up of 4.5×10^{-5} C in the dielectric between the wire grid must be determined.

Liemohn (1976) gives a field aligned electron flux of 2.4×10^{-3} A/m^2. With this flux it would take about 1.3 seconds for the dielectric to charge to the 4.5×10^{-5} C estimated (from Balmain, 1979) to produce a discharge. Since the highest duty cycle for 1.5 amp EBA firings is 25% (for FO-9), the charge up time is no less than 5 seconds since some vehicle neutralization will always be occurring. If an area of 25 m^2 is covered by the wire-Beta cloth combination, about 100 six inch square dielectric areas will exist and a maximum of 20 discharges per second might be expected, if any occur at all. The maximum average intensity of the discharges would be

$$E/BW = \frac{3.5 \times 10^{-7}}{.5 \times 10^{-1}} \; 10^{9} \; \mu \text{ V/m MHz}$$

$$= 7 \times 10^{3} \; \mu\text{V/m MHz}$$

$$= 77 \text{ db above } 1 \; \mu\text{V/m MHz,}$$

well below the ICD 2-19001 specifications of 99 db at 1.4 MHz to 91 db at 7 MHz.

4. CONCLUSIONS

Analysis of the effects of the ionospheric plasma environment has been carried out assuming that the shuttle might become electrically charged during SEPAC operations. The validity of this assumption was not addressed here. Arguements that the shuttle will reach high potentials are theoretical and are based on simplifying assumptions necessary to make the analyses. The counterargument is the experimental evidence from rocket data that those vehicles did not reach high potentials during electron accelerator operation. A resolution of the charging question awaits the first flight of SEPAC and is an important scientific question to be addressed during this flight.

With the fact firmly in mind that shuttle charging was <u>assumed</u> in this analysis, the following conclusions were reached:

- The wire-Beta cloth combination in the ionspheric plasma will tend to buffer the vehicle potential, that is, the higher the vehicle potential, the larger the effective collecting area will be.
- The Beta cloth will collect negative charge, will create large electric fields along the Beta cloth surface and may electrostatically discharge.
- If discharges occur, their duration is expected to be hundreds of nanoseconds and the maximum discharge rate for 25 m of wire-Beta cloth is estimated to be about 20 per second.
- If discharges occur, the instantaneous electric field one meter from the discharge is above the specification given in ICD 2-19001.
- If discharges occur, the average electric field one meter from the discharge is below the specification given in ICD 2-19001.

5. RECOMMENDATIONS

Since the only concern about the use of the wire-Beta cloth combination is the possibility of electrostatic discharges, the recommendations aim at eliminating the possibility of their occurrence. They are:

- Expose a six inch square of Beta cloth to a 7.5 kV electron beam with a current density of 10^{-2} Amperes/m^2 in a vacuum chamber and monitor it electrically and optically for discharging. The conditions for this test should be similar to the one reported by Balmain (1979). This test would emulate the worst condition expected for Space lab 1.
- If no discharges occur in the above test, repeat it with the same current density, but increase the voltage until discharges occur.
- If discharges occur at dangerously low voltages, consider the following.

  (1) Cover the Beta cloth with a material which resists electrostatic charging. GE claims to have tested a glass filter cloth that resists charging.

  (2) Use a smaller spacing of the wire on the Beta cloth. This should reduce the likelihood of discharges. If such an approach is considered, the combination should be tested as described above for discharges.

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FIGURE CAPTIONS

Figure 1
a) The geometry of the long wire in a plasma problem.
b) The potential near along wire in a plasma.
c) The electric field magnitude near a long wire in a plasma.

Figure 2
The "capture" distance from a wire at a potential with respect to the plasma potential.

Figure 3
The expected effective collecting area of the wire-Beta cloth combination planned for Spacelab 1.

Figure 4
a) Configuration used for experiment.
b) Dielectric surface potential.

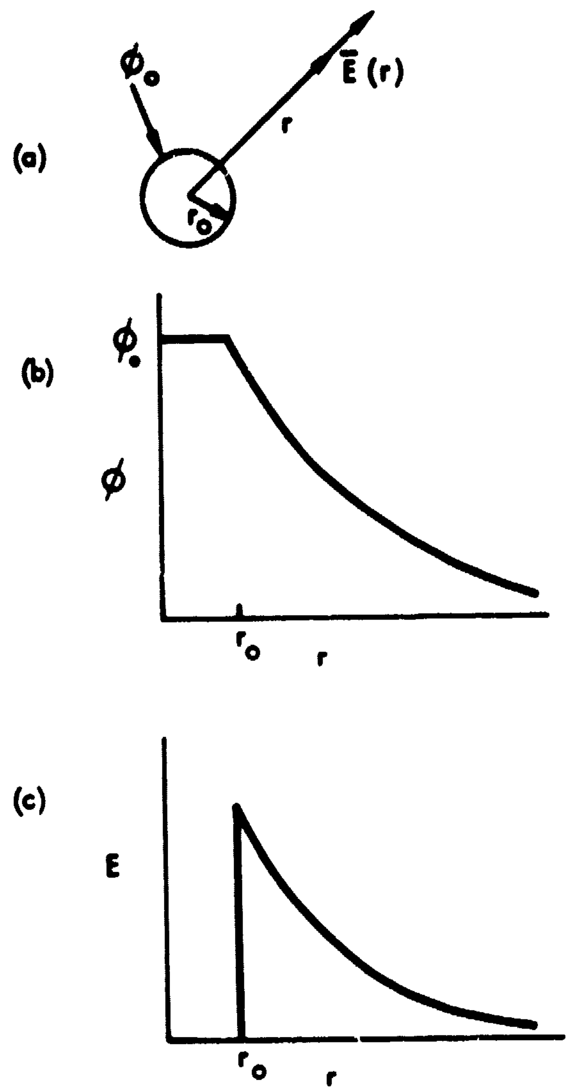


Figure 1

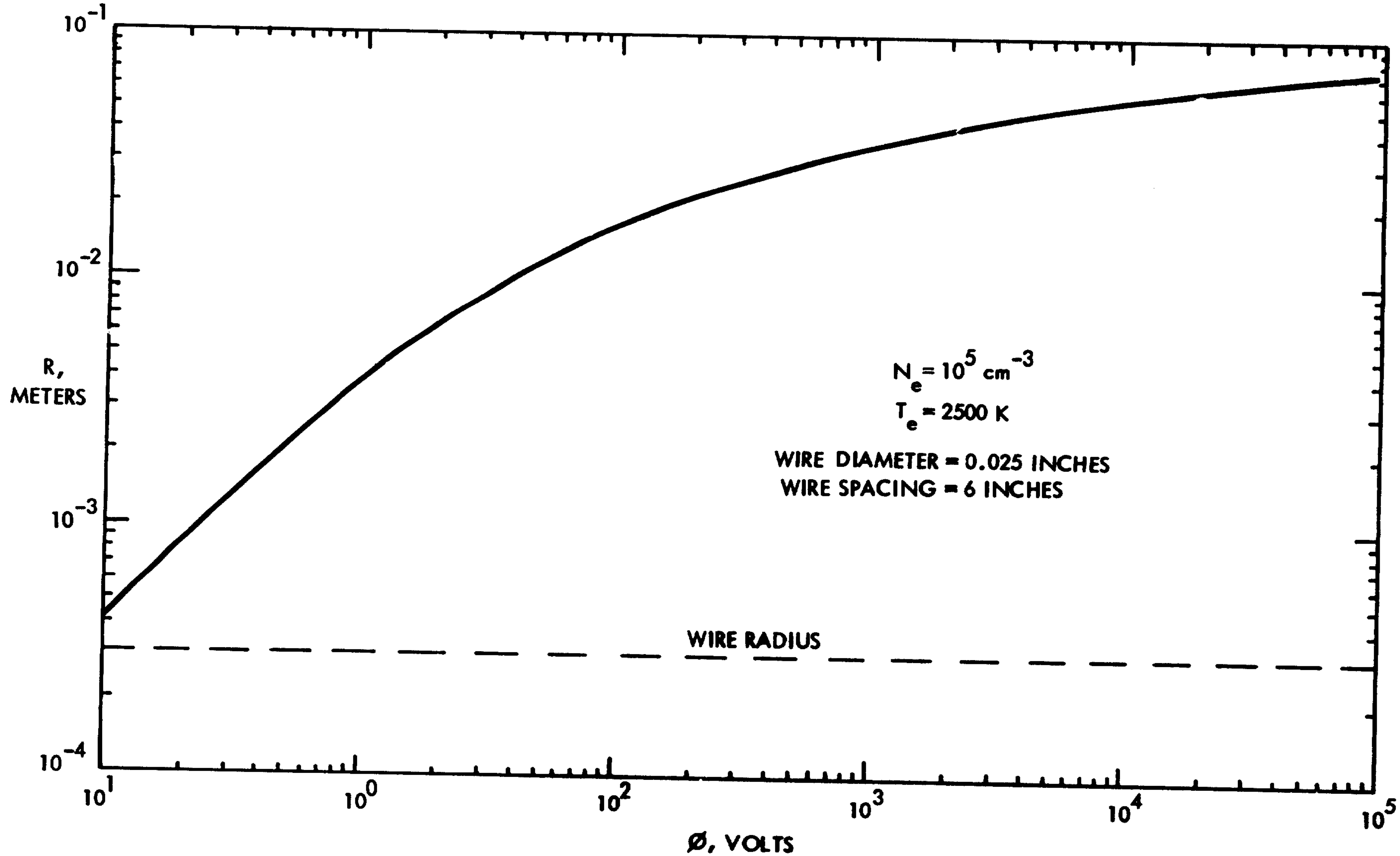

R, METERS
10^{-1}
10^{-2}
10^{-3}
10^{-4}
$N_e = 10^5\ cm^{-3}$
$T_e = 2500$ K
WIRE DIAMETER = 0.025 INCHES
WIRE SPACING = 6 INCHES
WIRE RADIUS
10^1
10^0
10^2
10^3
10^4
10^5
Ø, VOLTS

Figure 2

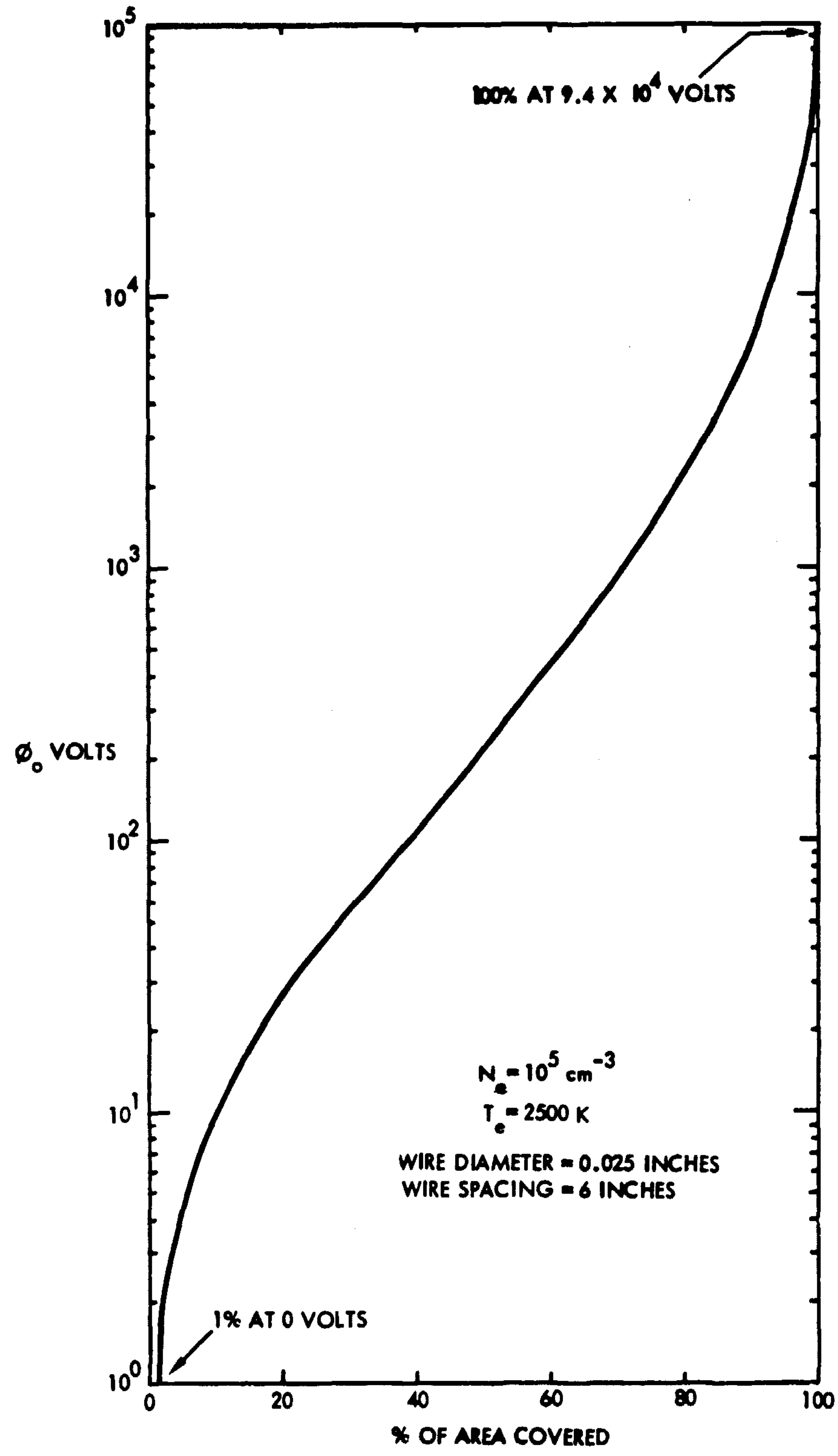
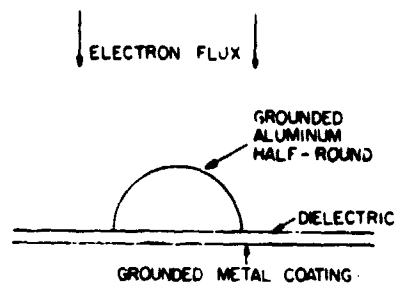
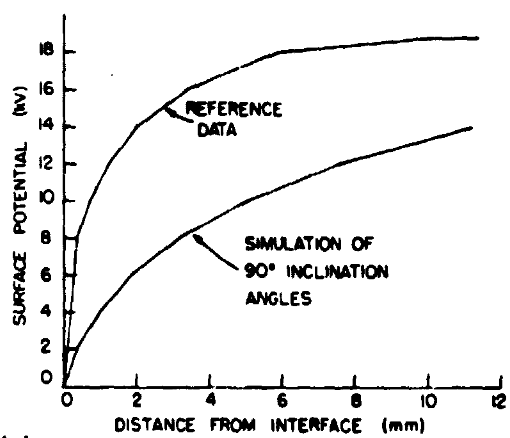

100% AT 9.4 X 10^4 VOLTS
ϕ_o VOLTS
$N_e = 10^5\ cm^{-3}$
$T_e = 2500\ K$
WIRE DIAMETER = 0.025 INCHES
WIRE SPACING = 6 INCHES
1% AT 0 VOLTS
% OF AREA COVERED
10^0
10^1
10^2
10^3
10^4
10^5
0
20
40
60
80
100

Figure 3


ELECTRON FLUX
GROUNDED
ALUMINUM
HALF - ROUND
DIELECTRIC
GROUNDED METAL COATING

(a)


18
16
14
12
10
8
6
4
2
0
SURFACE POTENTIAL (kV)
REFERENCE
DATA
SIMULATION OF
90° INCLINATION
ANGLES
0
2
4
6
8
10
12
DISTANCE FROM INTERFACE (mm)

(b)

Figure 4